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Abstract

This paper argues that trade specialization played an indispensable role in supporting the Industrial Revolution, allowing the economy to shift resources to the manufacture without facing food and raw materials shortage. In our artificial economy, there are two sectors – agriculture and manufacture – and the economy is initially closed and under a Malthusian trap. In this economy the industrial revolution entails a transition towards a dynamic Heckscher-Ohlin economy. The model reproduces the main stylized facts of the transition to modern growth and globalization. We show that two-sectors closed-economy models cannot explain the fall in the value of land relative to wages observed in the 19th century and that the transition in this case is much longer than that observed allowing for trade.

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1 Introduction

Most explanations of the Industrial Revolution tend to emphasize factors internal to the British or Western Europe economies. In this view, the escape from a Malthusian world with stagnant living standards to one with unprecedented and sustainable growth in productivity and wages is a phenomenon that can be explained entirely by domestic institutions and economic forces. For instance, North and Weingast(1989) stress that England had, at least since the 17th century, a unique set of laws protecting private property and contracts, developed markets for labor and products and restrictions on royal prerogatives that entailed the right incentives to innovation and investment. Those institutions did not exist, at that time, anywhere in the world.

Others, such as Landes (1969) and Mokyr(1990) place British technological advances in sectors such as textiles, steel and transportation, as the key factor behind the Industrial Revolution. The latter author (Mokyr, 2009) also emphasizes the impact of Enlightenment and a new set of ideas on science research and productive growth. Clark (2007) defends that a very subtle and long process of cultural change in England, that led people to adopt habits such as education, saving, hard work and abandon others such as violence and impatience, is the key element explaining growth acceleration. The so called unified growth theory (e.g., Galor and Weil(2000), Hansen and Prescott (2002), Lucas(2002), Desmet and Parente(2009)), in almost all cases emphasizes domestic mechanisms, although differing markedly across themselves.

Recently, however, some authors (e.g., Clark, 2007) have suggested that the institutions conducive to growth and economic preconditions were present in many other parts of 18th century world. Pomeranz (2000) suggests that densely settled core of *China* was indistinguishable from northwestern Europe as late as 1750 in terms of "commercialization, commodifications of goods, land, labor, market-driven growth and adjustment by households of both fertility and labor allocation to economic trends". Allen (2009) points out that property rights were at least as secure in France and possibly in China as in England and that there is no evidence of structural breaks in interest rates after 1688 so that the improved investment climate was not manifest in anything financial, a point also made by Clark(2007).

Hence, technological inventiveness and protection of private property were necessary to the Industrial Revolution, but it was not sufficient and, as stressed by Pomeranz (2000), not uniquely European. The point made by this and other authors - e.g., and O'Rourke and Williamson (2005) and Findley and O'Rourke (2007) - is that if British industry had been forced to source its raw materials domestically, rather than import them, prices would increase rapidly, as expanding levels of demand would be restricted by domestic land endowment. Nonfarm output increased almost ninefold between 1730 and the 1860s (Clark(2007)) but farm area per person went from about the same as western Europe to almost half and while population more than tripled in the course of the Industrial Revolution, domestic agricultural output did not even double.

If, indeed, there had been no agricultural revolution before 1860, we need to know what were the economic transformations that allowed the labor force to move towards the manufacturing sector. However, recent evidence provided by O'Rourke and Williamson (2005) suggests that another structural break has taken place almost at same time when the Industrial Revolution began: The first great globalization shock. The authors argue that it was only with the combined influence of the switch from mercantilism to free trade at the beginning of the 19th century as well as the development of new transport technologies and the sustained decline in its costs over the whole century that the great intercontinental price gaps began to disappear. As a consequence, it was only in the 19th century that the large-scale international trade became possible in some basic commodities as grain, animal products, coal and manufactured intermediates. Their estimates suggest that without the possibility of intercontinental trade, productivity growth would almost certainly have been much less than it actually was during the industrial revolution.

To sum up, it was international trade that first helped England and then Europe escape from Malthusian constraints and the ghost acres of the New World (Pomeranz 2000) had a crucial effect, permitting the expansion of industry without driving up raw materials costs to prohibitive levels.¹

¹ Although Pomeranz (2000) stresses the role of the colonies in easing the land restriction Clark, O'Rourke and Taylor (2008) argue that the key factor was trade, not trade with the New World colonies. For our purposes

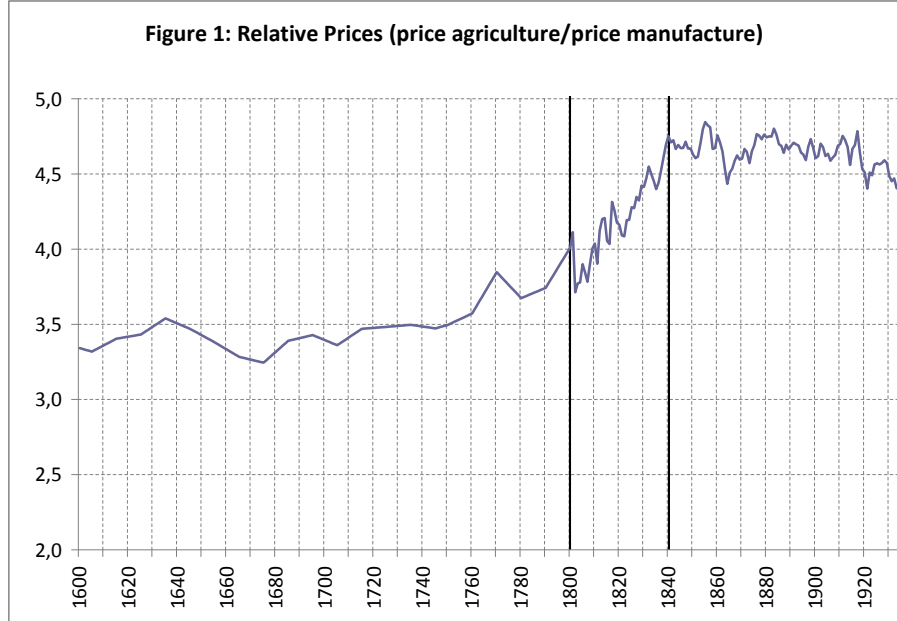
In this paper, we develop a growth model in which the expansion of the international trade takes place at about the same time that the technology in the manufacturing sector reaches a stage of development high enough to allow the economy to transit from stagnation to dynamic growth. We argue that trade specialization played an indispensable role in supporting the industrial revolution as it allowed the economy to shift resources to the production of manufactured goods without facing food and raw material crisis. Consequently, as opposed to one-good models (Hansen and Prescott(2005), Ngai(2004)) in which the industrial revolution is associated with a transition from the Malthus economy to the Solow economy, in this paper the industrial revolution entails a transition towards a dynamic Heckscher-Ohlin economy.

The problem with one-good models is that they cannot explain some important economic changes associated with the Industrial Revolution, namely the massive factor reallocation from the agricultural sector to the production of manufactured goods. This is so because in this type of model the industrial revolution is associated with the substitution of technologies which are used to produce the same good, instead of being associated with a reallocation of resources across sectors, as there appeared to be the case in England between 1750 and 1850, when workers left the agriculture sector towards the industry. This movement of factors of production from a stagnant (low productivity) sector to a dynamic (high productivity) one is required to the economy to take advantage of the faster productivity advance in the manufacturing sector and, as a consequence, to experience a higher increase in wages, a fall in rents and an inflate of the wage/rent ratio as observed in the period. Thus, for a model to be fairer with the empirical facts, it is necessary to assume that, at least, two goods are produced: agricultural products (using land, labor and capital) and manufactured goods (using capital and labor).

A second contribution of the paper comes from our calibration strategy. In the Malthus economy model one can derive the rate of technology growth in the manufacturing sector from the growth rate of relative prices, while in a two-sector economic model with growth it depends also on population and agriculture growth. In the open economy model, domestic relative prices are given in the international market. We use these facts to obtain the dates of

this question is not relevant and does not affect results.

globalization and growth acceleration from the relative prices series. The figure below presents the relative price of agricultural goods to manufacture goods in England, from 1600-1920.²



We used structural breaks tests - the Chow Breakpoint Test - to estimate the dates in which the slope of relative prices changes. We interpret the first break, around 1800, as purely technological growth acceleration: as innovation in manufactures intensifies, and so resources are shifted to the sector, prices in agriculture rise above those in manufacture. This is reflected in the steeper inclination of the relative price curve we observe after the turn of the century.

Subsequent to the second break, around 1840, relative prices stabilize. This is the impact of globalization: prices now are set in the international and not in the domestic market, otherwise relative prices would keep growing as there is no evidence that innovation and technology growth reduced in this period. This estimation is close to that in O'Rourke and Williamson (2002 and 2005), albeit a bit later. Hence, full integration of international markets occurred some decades after the acceleration of productivity growth in manufacture.

The calibration of the remaining parameters are standard and aim to match some targets of XVIII and XIX centuries England. The model is able to replicate the main facts of the

²This is the "papm" series from O'Rourke and Williamson(2002). We thank the authors for this and some of the series we use in the paper.

transition to modern growth. The ratio of land value to wages first increases after 1800 and then falls after 1840, as seen in the data. The share of labor force and capital employed in agriculture, as well as domestic production of agriculture goods, decrease to small figures. At the same time, trade becomes very significant. More importantly, we compare the results obtained with trade specialization with those obtained assuming closed economy (in this case, with and without an acceleration of technical progress in the agricultural sector). We conclude that the acceleration of the productivity growth in the agriculture could not, on its own, explain the fall in the value of land relative to wages observed in the 19th century. In our two-sectors-world, no matter what the technical progress in the agricultural sector is, its share of total labor force will always be large without trade, and land value as a proportion of wages converges to figures well above the observed. Moreover, the transition in this case is much longer than that obtained when trade is possible and does not reproduce the data.

Harley and Crafts (2000) and Clark, O'Rourke and Taylor (2008) use multisector computable general equilibrium models to study the Industrial Revolution, highlighting the importance of international trade, similarly to Stokey (2001). The latter article has some points in common with our approach. However, among many differences, it restricts its investigation to steady states while we are interested in studying the transition between Malthus and modern growth. By doing so we are able to model and calibrate globalization and the acceleration of technical progress as happening in different moments. Moreover, as we just said in the previous paragraph, by studying the transition path we are able to show some shortcomings of closed-economy models in the unified growth literature.

This article is organized in four sections in addition to this introduction. In the next section we present the model while the calibration procedure is presented in Section 3. Results are in Section 4, while in Section 5 some concluding remarks are made.

2 The model

2.1 General description

The model studied in this paper is a very simple two-good and two-sector version of the overlapping generations model. At early stages of development, the technology in the manufacturing sector is very incipient and international trade is not relevant. As a consequence, the resources of economy are heavily allocated in the agricultural sector and technological progress in the agriculture determines output growth. As technology in the agricultural sector evolves quite slowly, it is not able to offset population growth, so that the model behaves like the Malthus economy at this stage of development, that is, all per capita variables remain constant over time.

Given the assumptions on preferences and technology, resources will be allocated to both sectors in every period. At a certain moment there is a structural break in the technological progress in the manufacturing sector and resources are transferred at a faster rate to it from the agricultural sector. This movement of factors from the low growth sector to the high growth sector triggers economic growth. However, this reallocation is not possible - or will be much slower - if the economy is not open to international trade, since income growth would have caused a disequilibrium in the market of agricultural goods, raising its relative price. In order to capture the role of globalization in the industrial revolution, we assume that at a certain period after growth acceleration (possibly at the same time) international trade becomes relevant thereby allowing the economy to balance the agricultural market through importation. As a counterfactual, in some simulations the economy will be kept closed to trade during the transition to modern growth.

2.2 Technology

Technology in the agriculture sector is such that each firm in the sector (a "farm"), combines labor N_A , land L and capital K_A to produce an agricultural good denoted by Y_A . Each unit in the manufacturing sector corresponds to a factory and uses only labor N_M and capital K_M to produce a manufactured good denoted by Y_M . The technologies for the two sectors are as

follows:

$$Y_A = \gamma_A^{t-t_0} K_{At}^\phi N_{At}^\mu L^{1-\phi-\mu} \quad (1)$$

$$Y_M = \gamma_M^{t-t_0} K_{Mt}^\theta N_{Mt}^{1-\theta} \quad (2)$$

where $\gamma_A, \gamma_M > 1$ and $\gamma_M > \gamma_A$ denote the total factor productivity growth in the agricultural and manufacturing sector, respectively, $\theta \in (0, 1)$ is the capital share for the manufacturing technology; $\phi \in (0, 1)$ and $\mu \in (0, 1)$ are the capital share and the labor share in the agriculture; and t_0 denotes the period in which the industrial revolution begins.

In this economy, land is assumed to be in fixed supply and its total size is normalized to be 1. Additionally, given that the technologies above exhibit constant returns to scale, it is assumed that there is one production unit in each sector. Firms behave competitively in such a way that they decide how much of each input to employ in the production process in order to maximize their profits, taking the wage rate w , the rental rate for capital r_K , and the rental rate for rent r_L as given. Formally, the firm's problem in each sector can be written as follows:

$$\underset{K_{At}, N_{At}, L_t}{Max} \quad Y_{At} - r_{Kt}K_{At} - w_tN_{At} - r_{Lt}L_t, \quad s.t. \quad (1)$$

$$\underset{K_{Mt}, N_{Mt}}{Max} \quad P_t Y_{Mt} - r_{Kt}K_{Mt} - w_tN_{Mt}, \quad s.t. \quad (2)$$

where P_t denotes the price of manufactured good in terms of the agricultural good.

New investment in capital in period t takes the form of currently produced units of good A that are not used for consumption. As a consequence, the supply price of capital in terms of good A is one. The aggregate capital is determined by individual savings behavior, which will be described in the next subsection. We assume that capital is depreciated at 100% each period.

In the period t , given the price P_t and the aggregate stocks of capital K_t , labor N_t and

land L_t , competition in factor markets produces a wage rate w_t , an interest rate r_{Kt} , a land rent r_{Lt} , and allocations of capital K_{At} and labor N_{At} , that satisfy the equations:

$$w_t(K_{At}, N_{At}) = \mu \gamma_A^t K_{At}^\phi N_{At}^{\mu-1} = P_t(1-\theta) \gamma_M^t (K_t - K_{At})^\theta (N_t - N_{At})^{-\theta} \quad (3)$$

$$r_{Kt}(K_{At}, N_{At}) = \phi \gamma_A^t K_{At}^{\phi-1} N_{At}^\mu = P_t \theta \gamma_M^t (K_t - K_{At})^{\theta-1} (N_t - N_{At})^{1-\theta} \quad (4)$$

$$r_{Lt}(K_{At}, N_{At}) = (1 - \phi - \mu) \gamma_A^t K_{At}^\phi N_{At}^\mu \quad (5)$$

where we used the fact that $K_t = K_{At} + K_{Mt}$ and $N_t = N_{At} + N_{Mt}$.

We can combine equations (3) and (4) in order to obtain:

$$P_t(K_{At}, N_{At}) = \frac{\mu \gamma_A^t K_{At}^\phi N_{At}^{\mu-1}}{(1-\theta) \gamma_M^t (K_t - K_{At})^\theta (N_t - N_{At})^{-\theta}} = \frac{\phi \gamma_A^t K_{At}^{\phi-1} N_{At}^\mu}{\theta \gamma_M^t (K_t - K_{At})^{\theta-1} (N_t - N_{At})^{1-\theta}} \quad (6)$$

or, after some simplifications:

$$\frac{\mu}{(1-\theta)} \frac{K_{At}}{N_{At}} = \frac{\phi}{\theta} \frac{(K_t - K_{At})}{(N_t - N_{At})} \quad (7)$$

Equation (7) defines an efficient condition for the allocation of inputs (K_{At}, N_{At}) , given the aggregate stock of capital K_t and the labor force N_t in period t .

2.3 Preferences and demography

Households live for two periods and have preferences that depend on both goods in both periods of their lives. Young agents are endowed with one unit of labor time, which they supply inelastically. Out of their labor income they decide how much to consume of each good and how to divide their savings between capital and land, l . Agents do not work when old and receive income from renting land and capital to firms and from the sale of land to the young of the next generation.

Hence, an agent of generation t chooses consumptions (c_{At}^y, c_{Mt}^y) when she is young and

(c_{At+t}^o, c_{Mt+1}^o) when she is old and investment k_{t+1} and l_{t+1} in order to maximize her lifetime utility given by:

$$\alpha \ln(c_{At}^y - \underline{c}) + (1 - \alpha) \ln c_{Mt}^y + \beta[\alpha \ln c_{At+1}^o + (1 - \alpha) \ln c_{Mt+1}^o]$$

subject to:

$$\begin{aligned} c_{At}^y + P_t c_{Mt}^y + k_{t+1} + q_t l_{t+1} &= w_t \\ c_{At+1}^o + P_{t+1} c_{Mt+1}^o &= r_{Kt+1} k_{t+1} + (r_{Lt+1} + q_{t+1}) l_{t+1} \end{aligned}$$

where q_t is the price of land in period t , β is the intertemporal discount factor.

We assume that there is a minimum level of consumption \underline{c} for the good A . This assumption is in line with the literature on structural transformation (e.g., Duarte and Restuccia, 2005) and is adopted here so that the model to matches the share of labor force employed in the agricultural sector before the industrial revolution. For simplicity, we have assumed that the minimum consumption for the good A is only applied in the first period of individuals' life.

It is straightforward to show that the consumption of each good in each period is given by:

$$c_{At}^y = \frac{\alpha}{1 + \beta} [w_t(K_{At}, N_{At}) - \underline{c}] + \underline{c} \text{ and } c_{At+1}^o = r_{Kt+1} \frac{\beta\alpha}{1 + \beta} [w_t(K_{At}, N_{At}) - \underline{c}] \quad (8)$$

$$c_{Mt}^y = \frac{1 - \alpha}{1 + \beta} \frac{[w_t(K_{At}, N_{At}) - \underline{c}]}{P_t} \text{ and } c_{Mt+1}^o = r_{Kt+1} \frac{\beta(1 - \alpha)}{1 + \beta} \frac{[w_t(K_{At}, N_{At}) - \underline{c}]}{P_{t+1}} \quad (9)$$

and the individuals' savings and the price of land satisfy:

$$k_{t+1} = \frac{\beta}{1+\beta} [w_t(K_{At}, N_{At}) - \underline{c}] - q_t l_{t+1} \quad (10)$$

$$q_{t+1} = r_{Kt+1} q_t - r_{Lt+1} \quad (11)$$

Note that we are assuming that capital in this economy is obtained from the agricultural sector. In a sense we follow classical economists such as Adam Smith and Ricardo in considering that capital is seeds saved from the previous period. This assumption is not entirely necessary but aims to reproduce the fact that intermediate goods and investment goods in the period were heavily composed of agriculture goods.

We follow a Malthusian approach and assume that the population growth depends on the living standard, which is measured by the young individuals' consumption of good A . Thus, the number of individuals born in the period t is given by:

$$N_t = g(c_{At-1}) N_{t-1} \quad (12)$$

where $g(c_{At-1})$ denote the population growth rate as a function of c_{At-1} .

2.4 Equilibrium

The industrial revolution is interpreted as the transition from a closed Malthus economy (where per capita income is stagnant) to a small open economy with sustained growth. However, globalization and acceleration of technical progress need not start at the same time, although in the long-run one will observe both. The transition between the two economies is assumed to begin in t_0 . In this section, we present the definitions of the equilibrium for the economy in $t < t_0$ and in $t \geq t_0$.

The equilibrium in the (closed) Malthus economy is characterized by the stagnation of per capita income because technological progress at that stage of development is not able to overcome the pressure of population growth on the fixed land endowment. In order to generate a trajectory in which per capita variables remain constant over time, it is straightforward to

show (Hansen and Prescott, 2002) that the population growth rate needs to be equal to $\gamma_A^{\frac{1}{1-\phi-\mu}}$.

Thus, in the Malthus economy we have that $g(c_{At-1}) = g = \gamma_A^{\frac{1}{1-\phi-\mu}}$. Moreover, note that all endogenous variables in the model in the period t can be written in terms of the allocation of capital and labor between the sectors, so that we can define the equilibrium of the economy only in terms of (K_{At}, N_{At}) . Given these considerations, an equilibrium for the economy before the Industrial Revolution can be defined as follows:

Definition 1 *Given K_t , N_t , L , the price of land q_{t-1} and the population growth rate of $\gamma_A^{\frac{1}{1-\phi-\mu}}$, an equilibrium trajectory for the Malthus economy is given by a set of input allocations $(K_{At}^*, N_{At}^*) = (K_A^*, N_A^*)$ such that $\forall t < t_0$:*

- i) The equation (7) is satisfied;*
- ii) The market-clearing conditions are satisfied³:*

$$K_{t+1} = N_t k_{t+1} = N_t \frac{\beta}{1+\beta} [w_t(K_A^*, N_A^*) - \underline{c}] - q_t \quad (13)$$

where $N_t l_{t+1} = 1$.

$$N_t c_{At}^y(K_A^*, N_A^*) + N_{t-1} c_{At}^o(K_A^*, N_A^*) + N_t k_{t+1} = Y_{At} \quad (14)$$

$$N_t c_{Mt}^y(K_A^*, N_A^*) + N_{t-1} c_{Mt}^o(K_A^*, N_A^*) = Y_{Mt} \quad (15)$$

- iii) The price of land is given by:*

$$q_t = r_{Kt}(K_A^*, N_A^*) q_{t-1} - r_{Lt}(K_A^*, N_A^*) \quad (16)$$

We calculate this equilibrium as follows. First, we combine (14) with equation (7) in order to determine the optimal allocation of inputs across sectors, which is also consistent with the

³An alternative interpretation is that K represents intermediate goods rather than capital, given that investment (and so capital) goods come from the agricultural sector. Thus, when part of Y_A starts to be imported, part of it is eaten by the young, part eaten by the old and part goes to the production of other agricultural goods and (mostly) industrial goods.

market equilibrium. Once (K_{At}^*, N_{At}^*) have been calculated, prices and consumption choices can also be calculated using the appropriate equations derived above. In particular, after calculating r_{Kt} and r_{Lt} using (4) and (5), we can use (16) to obtain the price of land in t and then use (13) to calculate the stock of capital in the next period. This procedure is repeated up to $t = t_0 - 1$.

We assume that at a certain point $t = t_0$ there is a positive break in technical progress⁴. Global markets may or may not become integrated at this period, or it can happen in few periods later⁵. At this moment international price gaps are eliminated. As a consequence, the domestic price is now set at $P_t = \bar{P}$, where \bar{P} denotes the price of the good M in terms of the good A in the international market. For simplicity, we assume that domestic economy behaves as a small open economy so that it takes the price \bar{P} as given and any surplus (deficit) in the market of the good M (good A) is absorbed by international trade. Hence, market equilibrium equations (14) and (13) do not need to be satisfied in equilibrium any longer. Given these considerations, an equilibrium for the open economy is defined as follows:

Definition 2 *Given K_{t_0} , N_{t_0} , L , the price of land q_{t_0-1} and the international price \bar{P} , an equilibrium trajectory for the dynamic economy is given by a set of input allocations (K_{At}^*, N_{At}^*) such that $\forall t \geq t_0$:*

i) (K_{At}^*, N_{At}^*) is a solution of the following maximization problem:

$$Max_{K_{At}, N_{At}} : \gamma_A^t K_{At}^\phi N_{At}^\mu + P_t \gamma_{Mt}^t (K_t - K_{At})^\theta (N_t - N_{At})^{1-\theta} \quad (17)$$

subject to (7)

ii) The aggregate capital and the price of land are given by the following law of motions:

$$K_{t+1} = N_t k_{t+1} = N_t \frac{\beta}{1+\beta} [w_t(K_{At}^*, N_{At}^*) - \underline{c}] - q_t \quad (18)$$

$$q_t = r_{Kt}(K_{At}^*, N_{At}^*) q_{t-1} - r_{Lt}(K_{At}^*, N_{At}^*) \quad (19)$$

⁴More details of this in the Parameterization Section.

⁵According to our calibration, it will happen 40 years later, or two periods.

iii) The population growth rate is given by: $g(c_{At-1}(K_{At}^*, N_{At}^*))$.

Finally, we consider the case in which at $t = t_0$ the economy remains closed but experiences an acceleration of the technological progress in the agriculture (γ_A increases). In this case, the equilibrium for $t > t_0$ is calculated like the definition 1), but taken into account the effect of economic expansion on the population growth, that is, the population evolves according to (12).

3 Parameterization

The model is simulated from $t = -5$ to $t = 8$ and a period in the model corresponds to 20 years. The latter reflects the fact that life expectancy in pre-industrial societies was quite small and remained so until the beginning of the 20th century . .

The consumption of subsistence is chosen so that the model matches the share of the labor force allocated in the agricultural sector before the industrial revolution. According to Allen (2000), nearly 75% of the population in pre-industrial society was employed in agriculture. Thus, by setting $\underline{c} = 0.25$, the model generates a value of about 72 percent for $\frac{N_{At}}{N_t}$ in the Malthus economy.

The parameter α determines the share of income spent on the consumption of good A in the first period of individuals' life. Indeed, from (8), it can be seen, after some manipulation, that:

$$\frac{c_{At}^y}{w_t} = \frac{\alpha}{1 + \beta} \left(1 - \frac{\underline{c}}{w_t} \right) + \frac{\underline{c}}{w_t}$$

It is straightforward to show that as $w_t \rightarrow +\infty$, we have $\frac{c_{At}^y}{w_t} \rightarrow \frac{\alpha}{1+\beta}$. Thus, given the intertemporal discount factor β , the parameter α is calibrated in order to bring $\frac{\alpha}{1+\beta}$ close to its value on data. The share of food, beverages (non alcohol and alcohol), tobacco and clothing expenditures on total household income in the United Kingdom in 2003 was 16.1%, according to Laborsta Internet (<http://laborsta.ilo.org>). It reaches 21.9% of household income net of

taxes⁶. We set $\alpha = 0.35$, corresponding to a value for $\frac{c_{At}^y}{w_t}$ equal to 0.175. Other values were used to check the robustness of our results.

We assumed the labor share to be 0.6 in both sectors, so that capital share is 0.4 in the manufacture. We set land share in the agriculture sector to 0.3, so that capital share in this sector be only 0.1.

The most novel aspect of our calibration is the estimation of the structural breaks in the growth rate and in the trade regime. From the model one can show that the growth rate of relative prices in the Malthus economy is equal to the technical progress in the manufacture. Relative price is given by:

$$P_t = \frac{\mu \gamma_A^{t-t_0} K_{At}^\phi N_{At}^{\mu-1}}{(1-\theta) \gamma_M^{t-t_0} (K_t - K_{At})^\theta (N_t - N_{At})^{-\theta}} \quad (20)$$

so that its growth rate is:

$$\frac{P_{t+1}}{P_t} = \frac{\mu \gamma_A^{t+1-t_0} K_{At+1}^\phi N_{At+1}^{\mu-1}}{\mu \gamma_A^{t-t_0} K_{At}^\phi N_{At}^{\mu-1}} \frac{(1-\theta) \gamma_M^{t-t_0} (K_t - K_{At})^\theta (N_t - N_{At})^{-\theta}}{(1-\theta) \gamma_M^{t+1-t_0} (K_{t+1} - K_{At+1})^\theta (N_{t+1} - N_{At+1})^{-\theta}}$$

that simplifies to

$$\frac{P_{t+1}}{P_t} = \frac{\gamma_A}{\gamma_M} \frac{\left(\frac{K_{At+1}}{K_{At}}\right)^\phi \left(\frac{N_{At+1}}{N_{At}}\right)^{\mu-1}}{\left(\frac{K_{t+1}-K_{At+1}}{K_t-K_{At}}\right)^\theta \left(\frac{N_{t+1}-N_{At+1}}{N_t-N_{At}}\right)^{-\theta}}.$$

using the fact that capital-labor ratio is constant, capital and labor grows at the same ratio

g

$$\frac{P_{t+1}}{P_t} = \frac{\gamma_A}{\gamma_M} \frac{g^{\phi+\mu-1}}{g^{\theta-\theta}} = \frac{\gamma_A}{\gamma_M} g^{\phi+\mu-1}$$

It is easy to show that $g = \gamma_A^{\frac{1}{1-(\phi+\mu)}}$, so that

$$\frac{P_{t+1}}{P_t} = \frac{\gamma_A}{\gamma_M} \frac{1}{\gamma_A} = \frac{1}{\gamma_M}. \quad (21)$$

When modern growth starts, but the economy remains closed, the growth of relative prices follows a different regime, which is a function not only of γ_M but also of γ_A and

⁶ For the U.S., France and Netherlands it was 14.%, 31% and 19%.

population growth⁷. In the open economy, relative prices are set in the international market, characterizing a third regime for P_{t+1}/P_t . We employed the Chow test to estimate breaks in the growth rate of relative prices. The central idea of this test is to separate the initial sample in several sub samples and to verify if the original regression delivers distinct estimators to each sub sample. If the test identifies different coefficients between sub samples, exists evidence of structural break in the econometric model⁸.

We used the "*papm*" series from O'Rourke and Williamson (2002), which measures the relative prices of agricultural goods to manufacture goods in England, from 1500 to 1920 (the inverse of P_t of our model). It is displayed in Figure 1. Two breaks were estimated in this series, one in 1800 and the other in 1840. In the first case, relative prices become more positively sloped after the break, which could imply an acceleration of the growth rate of the technical progress in manufacture. Our interpretation in this case is the start of modern growth.

After the second structural break in 1840, prices fluctuate around a horizontal trend. As we said in the introduction, there is no evidence of stagnation in manufacture in the second half of the 19th Century. So, this can only mean that relative prices are no longer set by domestic technical progress and other local factors, but are determined in the international market. Hence, 1840 is the estimated date of "globalization"⁹.

The next step is to estimate γ_M for the different periods. Here we follow part of the unified growth literature. We set this growth rate for the Malthus period to zero¹⁰. There

⁷More precisely, it is possible to show, after lengthy calculations that in the long-run

$$\frac{P_{t+1}}{P_t} = \frac{1}{\gamma_M} \left(\frac{\gamma_A}{\gamma_N^{1-(\phi+\mu)}} \right)^{\frac{1-\theta}{1-\phi}}$$

where γ_N is the population growth rate, assumed to be exogenous.

⁸More specifically, the model is partitioned in two or more sub samples, each one with more observations than the number of parameters to be estimated. The Chow Structural Break Test basically compares the squared sum of residuals of the regression model with the entire sample with squared sum of residuals resultant of the same equation for sub samples. It uses a F test in which the null hypothesis is no break in the period. In the present case we test for structural break for the trend in prices, and the model was a RA(1).

⁹Of course, globalization did not happen in a given year, it was a process whose rhythm was influenced by a series of trade liberalization laws and measures and by innovations in transportation technology. The estimated break is capturing the year in which there is clear evidence in the data of a change of regime.

¹⁰Using equation (21) we ran an OLS regressions of $\ln(\text{papm})$ on a trend and a constant for this period to estimate γ_M . The estimated value was positive, but very small. Setting it to zero has no effect on results.

are two alternative strategies to calibrate γ_M in the modern-growth period, and they deliver different values. One is to use estimates, from the economic history literature, of technical progress in the manufacture in 1800-40 or in the 19th century. In this case, it ranges from 1.8% a.a. (McCloskey, 1981) to around 1% (Harley, 1993). The problem in this case is that it will underestimate aggregate growth in later periods. The alternative is to pick γ_M in order to match growth in the 20th century, after transition. The growth rate of output per worker in the U.K., during the second half of the previous century was 2.2% according to the Penn-World Tables. The problem now is that it overestimates technical progress in the manufacture in the 19th century. We chose the latter procedure as it is more common in the growth literature

As we abstract from endogeneizing demographic decisions, we chose, to simplify matters, to follow Hansen and Prescott (2002) in the calibration of demographic transition during the Industrial Revolution. According to the authors, the population growth rate seems to be linearly increasing in consumption until living standards being twice as large as in the Malthus equilibrium. Afterwards, the population growth rate is linearly decreasing in consumption until living standards being 18 times the level observed in the Malthus steady state. For simplicity, it is assumed that the population remains constant after that point. We use the consumption of good A of the young as a measure of the living standards in the model. Thus, the population growth rate for $t \geq t_0$ is given by:

$$g(c_{At}) = \begin{cases} \gamma_A^{\frac{1}{1-\phi-\mu}} \left(2 - \frac{c_{At}}{c_{At_0-1}} \right) + 2 \left(\frac{c_{At}}{c_{At_0-1}} - 1 \right) & \text{if } c_{At} < 2c_{At_0-1} \\ 2 - \frac{c_{At} - 2c_{At_0-1}}{16c_{At_0-1}} & \text{if } 2c_{At_0-1} \leq c_{At} \leq 18c_{At_0-1} \\ 1 & \text{if } c_{At} > 18c_{At_0-1} \end{cases}$$

4 Results

The economy is simulated for 14 periods initiating at $t = -5$, the start of modern growth at $t = 0$ and globalization at $t = 2$. Figures 2 and 3 analyze the behavior of resources allocation across sectors over time by showing the trajectories of the shares of labor force and capital stock in the agricultural sector for three different scenarios. In the first, Malthus

economy, the per capita output and wages are constant over time and, as a consequence, there is no structural transformation as the economy evolves since the $\frac{N_{At}}{N_t}$ and $\frac{K_{At}}{K_t}$ remain unchanged. In the second, "growth" there is no trade but the manufacturing sector experiences an acceleration of technical progress in $t = 0$ and in the third, "international trade," there is technical progress at $t = 0$ and international trade after $t = 2$. The latter represents our benchmark simulation.

Figure 2: Share of the labor force employed in the agricultural sector

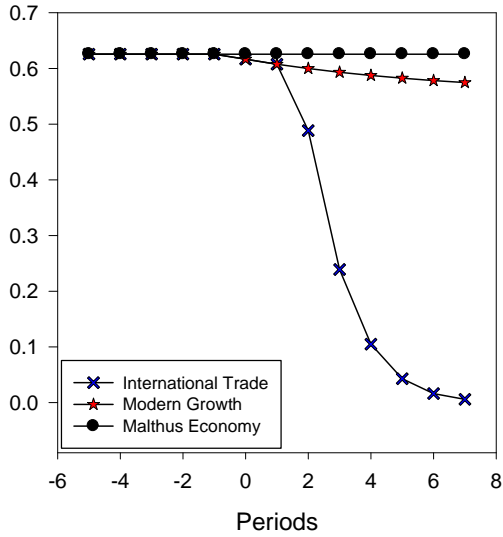
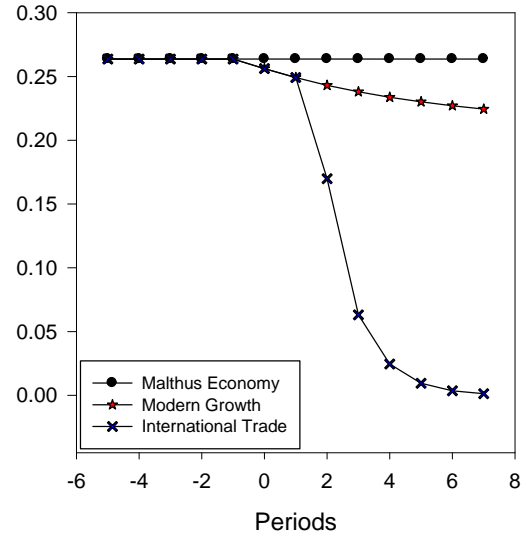


Figure 3: Share of capital employed in the agricultural sector



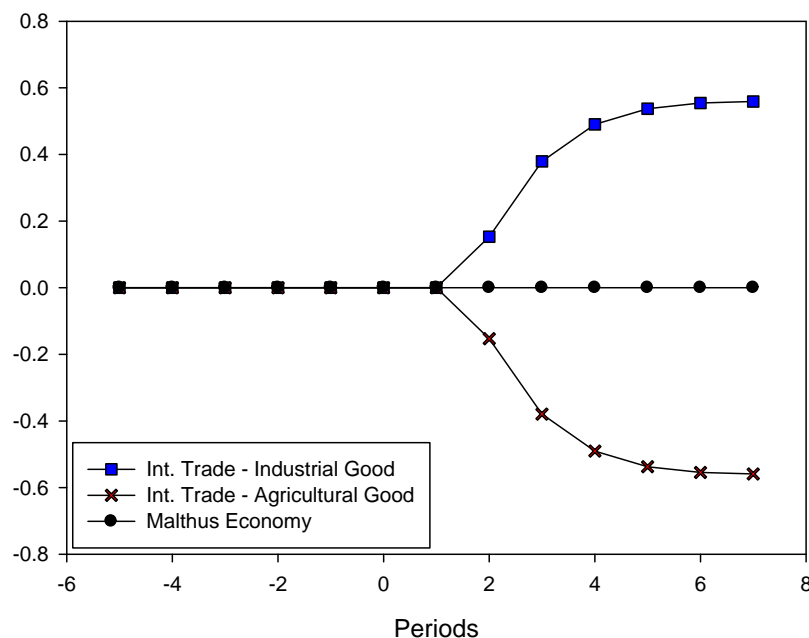
The model is able to replicate structural transformation. As technical progress accelerates, labor and capital are shifted to manufacture. However, while the economy is still closed - the "Growth " line or the two first period of the "International trade " - this movement is very slow: without international trade, labor share in the agriculture, after 120 years (six periods) of $t = 0$, was still above 50% of the total. In contrast, when trade is relevant the structural transformation speeds up and 80 years after the start of the Industrial Revolution only 10% of the labor force still remains in the agriculture sector. According to Clark(2007) in 1860 only 21% of workers were employed in the agriculture. The trajectories for capital are similar.

Even when we assume that in $t = 0$ occurs an acceleration in the technological progress in

the agricultural sector the model suggests that, in the closed-economy model, the transition from the agricultural economy towards an industrial economy would be much longer than that observed in the data. This is so because in the economy with two goods without international trade, the balanced growth trajectory requires that a massive amount of resources remains allocated in the agricultural sector over time, otherwise there would be a disequilibrium in that sector as the production of good A decreases with the reallocation of inputs towards the production of good M .

In contrast, the opening of the economy to the global market allows factors reallocation to take place fast, since any market disequilibrium can be absorbed by international trade. As a consequence, a relatively fast structural transformation can only be explained, in a specific factors world in which two commodities are produced, by a globalization shock which entails a great increase in the intercontinental trade. Figure 4 below presents the pattern of trade of the benchmark simulation:

Figure 4: International trade-output ratio



Although numbers are not in line with those observed in 19th century England (among

other reasons because there are no capital flows in the model, so that imports and exports values have to balance every period) it reproduces qualitatively the growth of food and raw material imports and of manufacture exports. British imports went from 20 million pounds in 1784-6 to 151 million pounds in 1854-1856, while in the same period imports of raw material went from 9.4 to 90 million pounds. Still in the same period, exports increased ten fold while the share of exports out of GDP more than doubled from 1700 to 1851¹¹.

Figures 5 below presents the behavior of the land rent-wages ratio. By construction it is constant in the Malthus period. According to the data (O'Rourke and Williamson (2002)), it increased very slowly in the 18th century, less than 9% during the whole period¹². However, in the first four decades of 19th century, land value to wages rose by almost 40% - more than six times faster than in the previous century - and only after 1840 it starts to fall, as the line "Data" clearly shows¹³.

As technical progress speeds up in manufacture and resources are transferred to the sector, the prices of agriculture goods increase and the distribution of income changes, hurting workers whose consumption basket at that time was mostly made up of food and beverage goods. The model is able to reproduce this fact in the first two periods after the start of the Industrial Revolution, when the economy is still closed. Feinstein (1998) had already noted that workers did not benefit from growth in the beginning of the Industrial Revolution, but most of the recent literature ignores this fact. In these articles the start of the transition to modern growth and the fall of the ratio of land value to wages are simultaneous. However, our simulations under-estimate the increase of the land rent-wages until period two (i.e., "1840"). Apparently, there were other factors besides technical progress in manufacturing affecting

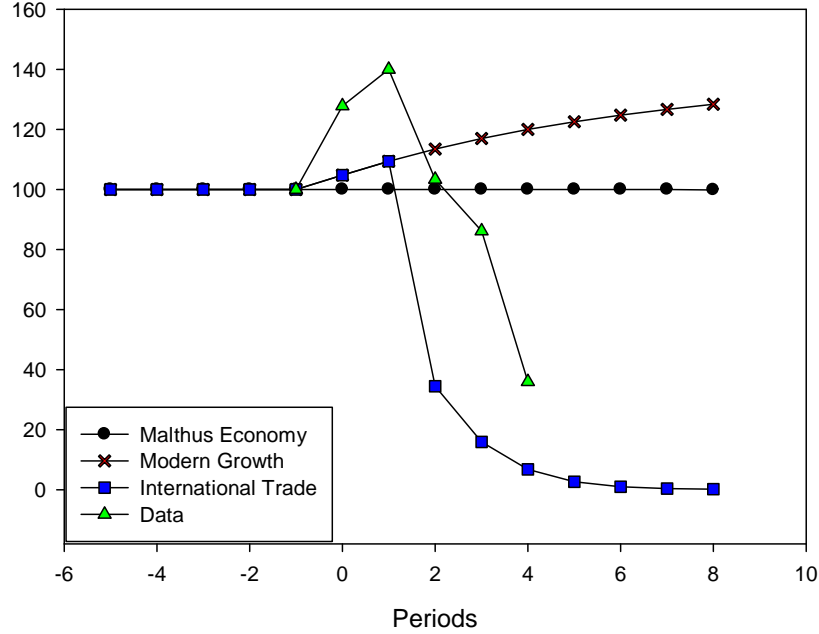
¹¹All figures from Findlay and O'Rourke (2007).

¹²Note, however, that land rent to wages ratio increased substantially in the 16th and 17th centuries.

¹³The land rent-wage ratio displayed in the "Data" line is from O'Rourke and Williamson (2005).

income distribution in early Industrial Revolution that are not present in the model.

Figure 5: Land value-wages ratio

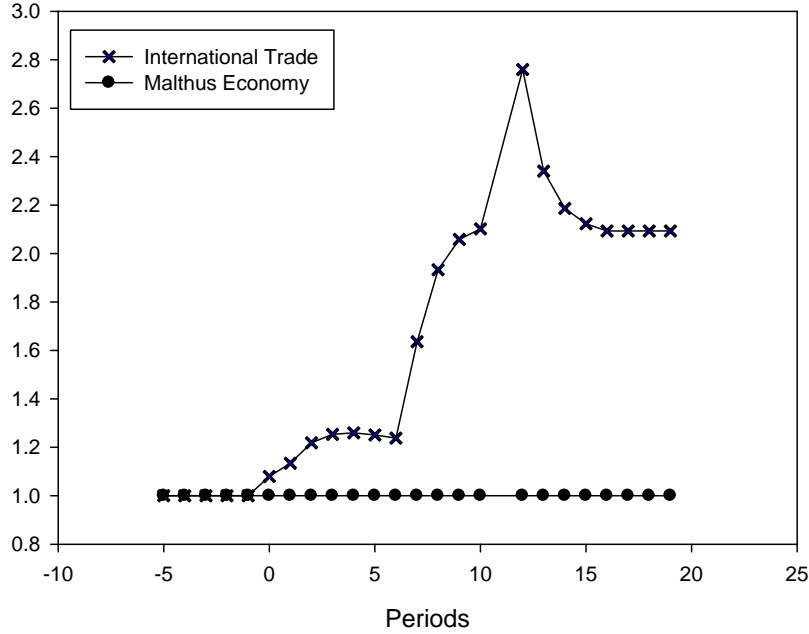


It is only after the start of trade specialization that wages increase relative to land rent. In this case, the model shows that global market integration cuts the link between factor prices and domestic land-labor ratio, allowing the economy to overcome the pressure of the population growth - and the transfers of factors to manufacture - on the fixed land endowment. Moreover, the model matches the data reasonably well, as both the "Data" and "International Trade" lines fall sharply after 1840. In contrast, as shown by the "Growth " simulation in Figure 5, had the economy remained closed, the land rent-wages ratio would continue to expand, exactly the contrary to the observed trend. This is another evidence that trade specialization is key to explain stylized facts of the transition to modern growth in multi-sector economies.

Many had noted (e.g., Mokyr (1993) and Harley(1993)) that the growth rate of aggregate output took many decades after the start of the Industrial Revolution to speed up. The pattern was a small and continuous acceleration of growth rate. As the share of agriculture

in total output was very high in the Malthusian period, and its rate of growth small, there is a composition effect and only when the manufacturing sector becomes dominant is that aggregate growth gets close to the current figures. This is reproduced in the simulation displayed in Figure 6 below.

Figure 6: Output per capita growth rate

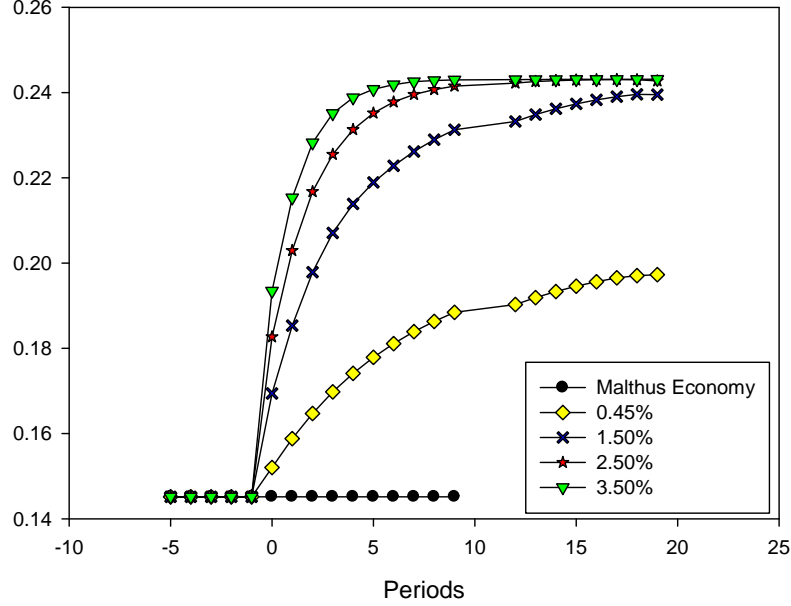


From 1800 to 1880, GDP per capita in England experienced an expansion of 120%, according to Maddison(2003). Our benchmark model (The "International Trade") is able to match very closely this figure, missing it by less than 10%. Moreover, growth accelerates, reproducing the data, after two periods (i.e., after "1840"), when the economy starts to trade with the rest of the world. In the closed-economy model, however, growth is constant after 1800 on and, worst still, after four periods GDP per capita increased by less than 40%.

Finally, note that without international trade even a large acceleration of productivity growth in the agricultural sector cannot account for the fall in the value of land-wages ratio and thereby cannot explain the reduction of income inequality associated with the industrial revolution. Figure 7 below presents land value-wages trajectory for different rates of

technological progress in agriculture:

Figure 7: Land value-wages ratio for different agricultural productivity growth rate



This happens because in the balanced growth path of the closed economy factor prices and land and labor endowments are associated over time. As a consequence, the growth of output per capita and wages must be governed by the technological progress in the agricultural sector. However, given that this sector is much less intensive in capital than the manufacturing sector, the economic growth under that trajectory is lower and thereby cannot surpass the population growth, which leads the value of land-wages ratio to increase during the transition. In the limit, the per capita economic growth rate without commerce converges to $\gamma_A^{\frac{1}{1-\phi}}$. Moreover, given the large share of labor force still allocated to the agriculture after convergence (see Figure 2), the value of land relative to wages also remains high in the new steady state.

5 Conclusion

Modern growth, understood as the escape from Malthusian trap, started before the first wave of globalization. Trade liberalization and innovations in transportation technology in mid 19th century allowed for the integration of markets and for very strong growth in international exchange. Technical progress in manufacture accelerated decades before. According to our estimates, some forty years before, although many studies set it at different dates (in general in late 18th century).

This paper does not provide a new theory of the Industrial Revolution, it does not explain why it happened in England and why at that given period. It also does not explain the boost in trade. Our main point is to show, by simulating a recursive model calibrated to 18th and 19th centuries England, that without trade one cannot fully explain Industrial Revolution. The reason is very simple: without international commerce - either with colonies or previous colonies or with any other region of the world - England would not be able to shift resources to the production of manufacturing goods at the rate one observes in the data. This point had been made before, but we measured and showed that the transition period in the closed economy model would be considerably longer than that observed in the data and that many variables (e.g. the share of labor force in agriculture) would converge to figures very distant from the actual ones.

Moreover, two-sector closed-economy models are not able to reproduce the fall in the ratio of land values to wage that started in the middle of the 19th century. In this model, this ratio increases continually in the whole period and not only during the first two. In contrast, when we allow our artificial economy to trade the land value to wages ratio falls, as the import of food and raw materials relax the land restriction.

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